APPENDIX L

Fission Foil Detector Calibrations with High Energy Protons

by

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Introduction

Fission foil detectors (FFDs) are passive devices composed of heavy metal foils in contact with muscovite mica films. The heavy metal nuclei have significant cross sections for fission when irradiated with neutrons and protons. Each isotope is characterized by threshold energies for the fission reactions and particular energy-dependent cross sections. In the FFDs, fission fragments produced by the reactions are emitted from the foils and create latent particle tracks in the adjacent mica films. When the films are processed surface tracks are formed which can be optically counted. The track densities are indications of the fluences and spectra of neutrons and/or protons.

FFDs have previously been used for spaceflight measurements (Benton et al., 1982-1983; Benton et al., 1978; Benton et al., 1981; Frank et al., 1990; Dudkin et al., 1992). In cases where the proton contribution to track densities can be subtracted out, the FFDs can be used as high energy (>1 MeV) neutron dosimeters. These detectors have been calibrated with neutrons of energies up to ~15 MeV and found to have efficiencies $\epsilon = 1.16 \times 10^{-5}$ tracks/neutron barn (Pretre et al., 1968), where "thick" foils are used (the thickness of the foils exceeds the ranges of the fission fragments produced so that maximum efficiency is achieved). There have been no calibrations performed with nucleons of higher energies or with FFDs having threshold energies above 15 MeV. In the past, detection efficiencies have been calculated using the low energy neutron calibration and published fission cross sections for neutrons and protons. The problem is that the addition of a large kinetic energy to the (n,nucleus) or (p,nucleus) reaction could increase the energies and ranges of emitted fission fragments and increase the detector sensitivity as compared with lower energy neutron calibrations.

High energy calibrations are the only method of resolving the uncertainties in detector efficiencies. At high energies, either proton or neutron calibrations are sufficient since the cross section data, plotted in Figure 1 (Lomanov et al., 1979; Wollenberg and Smith, 1969; Stehn et al., 1965), show that the proton and neutron fission cross sections are approximately equal.

Experiment

High energy proton beams have been utilized at the Lawrence Berkeley Laboratory BEVALAC and at Harvard Cyclotron Laboratory (HCL). Beam energies were 1.8 and 4.9 GeV at the BEVALAC and 80 and 140 MeV at HCL. All irradiated FFDs were assembled with thick foils. During the irradiations the proton beams were incident normal to one surface of the detectors. The two mica films therefore measure the tracks of fission fragments emitted backward (opposite to the proton direction) and forward (in the direction of the protons), respectively (Figure 2).

For the BEVALAC irradiations, the proton doses were monitored by arrays of TLDs (TLD-700) held in acrylic plates. The plates were aligned with the FFDs during the irradiations. At HCL, their calibrated ion chambers were used to determine the doses. In each case the proton fluence is found from

$$F_p = \mathrm{Dose(rad)}/[1.602 \times 10^{-8} \times \frac{dE}{dX}\,(\mathrm{MeV\cdot cm^2\cdot g^{-1}})]$$

After the irradiations, the mica films were etched in 50% HF for 1 hr at 21°C to reveal the fission fragment tracks. They had been etched for 3 hr prior to the irradiations to enlarge the latent fossil tracks. Average track densities were measured by scanning several strips across each film under an optical mocroscope at 200X or 430X, depending on track densities. Backgrounds were counted on reverse sides of the films.

Track densities from aged ^{238}U foils are reduced due to oxidation. This was compensated for by dividing the measured track densities by 0.7, so that the results are consistent with new, unoxidized foils. The background due to spontaneous fissions in the ^{238}U foils were measured by storage of assembled FFDs.

Measurements

The measured detector efficiencies are given in Table 1. The track densities on the two mica films (backward and forward) have been averaged for each fission foil, as would be done in space measurements. In all cases the track density in the forward (beam) direction was greater than in the backward direction, showing that beam energies have a distinct effect on fission fragment ranges. The ratios of backward-to-forward track densities with better statistics varied from 0.45 (1.8 GeV protons on ^{181}Ta) to 0.85 (140 MeV protons on Pb) but the data are too sparse to determine variations as functions of beam energy or atomic number of the foil.

The standard deviations (σ) for the 1.8 and 4.9 GeV measurements are in the range of 7 to 15%. This is mainly due to uncertainties in proton fluences caused by gradients across the detectors during the irradiations. The track counting statistics were about 2-4%. The beam was uniform across the detectors at HCL, resulting in smaller σs in the 80 and 140 MeV measurements.

The efficiency measurements are plotted in Figure 3 along with some calculated neutron efficiencies for ^{238}U and ^{232}Th at lower energies. The cross section curves (Figure 1) have been used as guides in filling in the efficiency curves over a wide energy range. The ^{232}Th measurement at 4.9 GeV does not fit in with other measurements or with projections from the cross sections. The reason for this could not be determined.

Conclusions

A beginning has been made to the calibration of fission foil detectors to high energy nucleons. Measured sensitivities above 1 GeV (tracks/nucleon) are higher by factors of approximately 2-3 than those which would be calculated using published fission cross sections and the efficiency equation derived from low energy neutron calibrations. The calibrations will be improved by measurements at a greater number of energies. The energy range of interest in space applications extends to 100 GeV (Armstrong and Colborn, 1990) so the published fission cross section curves will continue to be useful in supplementing measurements.

REFERENCES

Armstrong T.W. and B.L. Colborn (1990), Scoping estimates of the LDEF satellite induced radioactivity. SAIC, Report No. SAIC-90/1462.

Benton E.V., R.M. Cassou, A.L. Frank, R.P. Henke and D.D. Peterson (1978), Space radiation on board Cosmos 936--U.S. portion of experiment K206, in: Final Reports of U.S. Plant and Radiation Experiments Flown on the Soviet Satellite Cosmos 936 (S.N. Rosenzweig and K.A. Souza, eds.). NASA TM 78526.

Benton E.V., R.P. Henke, A.L. Frank, C.S. Johnson, R.M. Cassou, M.T. Tran and E. Etter (1981), Space radiation dosimetry aboard Cosmos 1129--U.S. portion of experiment K309, in: Final Reports of U.S. Plant and Radiation Experiments Flown on the Soviet Satellite Cosmos 1129 (M.R. Heinrich and K.A. Souza, eds.) NASA TM 81288.

Benton E.V., R.P. Henke, A.L. Frank, R.M. Cassou, C.S. Johnson and M.T. Tran (1982-1983). Final Dosimetry Reports for STS-3, STS-4, STS-5, STS-6, TR-54, -56, -57, -58, University of San Francisco Physics Research Laboratory.

Dudkin V.E., Yu.V. Potapov, A.B. Akopova, L.V. Melkumyan, Sh.B. Rshtuni, E.V. Benton and A.L. Frank (1992), Neutron fluences and energy spectra in the Cosmos-2044 Biosatellite orbit, Nucl. Tracks Radiat. Meas. 20(1), 139-141.

Frank A.L., E.V. Benton, E.R. Benton, V.E. Dudkin and A.M. Marenny (1990), Radiation experiments on Cosmos 2044: K-7-41, Parts A,B,C,D,E, TR-76, University of San Francisco Physics Research Lab.

Lomanov M.F., G.G. Shimchuk and R.M. Yakovlev (1979), Solid state detectors of fission fragments for the REM dose measurement of mixed proton and neutron radiation. Hlth. Phys. 37, 677-686.

Pretre S., E. Tochilin and N. Goldstein (1968), Solid state detectors of fission fragments for the REM-dose measurement of mixed proton and neutron radiation. Hlth. Phys. 37, 677-686.

Stehn J.R., M.D. Goldberg, R. Wiener-Chasmon, S.F. Mughabghab, B.A. Magurno and V.M. May (1965), Neutron Cross Sections Vol.III, BNL 325.

Wollenberg H.A. and A.R. Smith (1969), Energy and flux determinations of high-energy nucleons, UCRL-19364.

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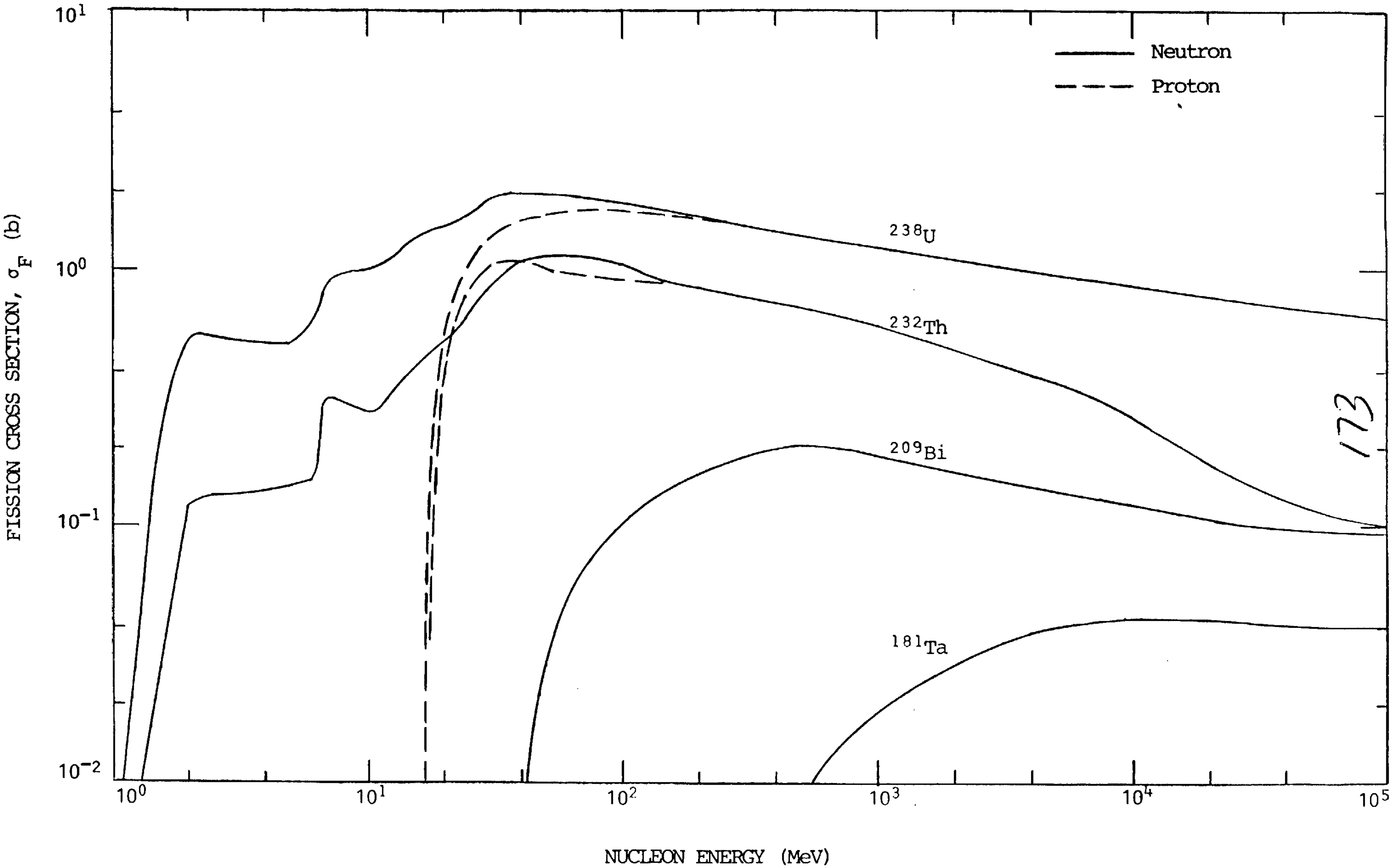

Fig. 1. Fission cross sections for neutrons and protons incident on heavy metal foils

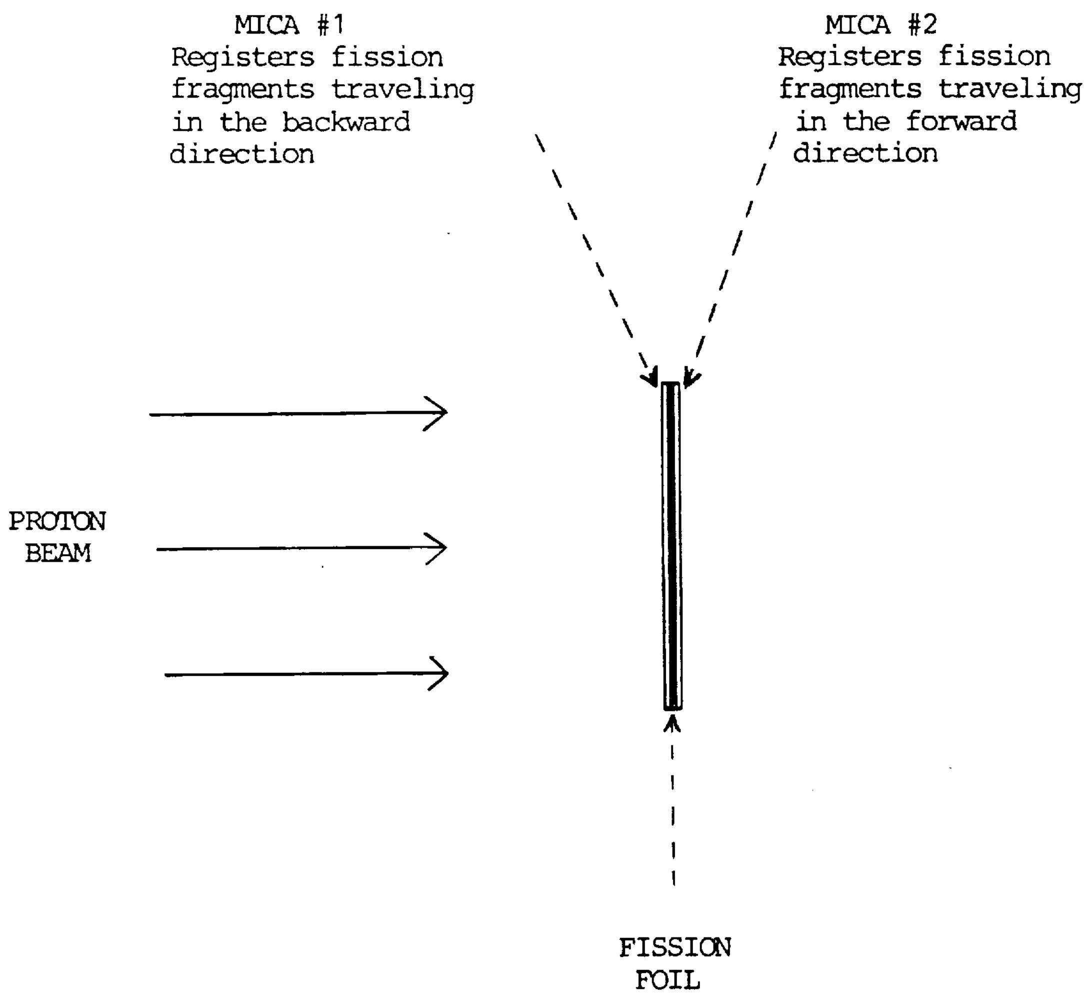

Fig. 2. Sketch of the experiment

Table 1. MEASURED SENSITIVITIES OF FISSION FOIL DETECTORS

Fission Foil	14 MeV Neutrons* (tracks/n)	80 MeV Protons (tracks/p)	140 MeV Protons	1.8 GeV Protons (tracks/p)	4.9 GeV Protons (tracks/p)
^{181}Ta	0	0	---	$9.8\pm0.9\times10^{-7}$	$1.59\pm0.15\times10^{-6}$
^{209}Bi	0	$6.21\pm0.25\times10^{-7}$	$1.43\pm0.05\times10^{-6}$	$2.65\pm0.32\times10^{-6}$	$2.60\pm0.18\times10^{-6}$
^{232}Th	4.76×10^{-6}	$1.32\pm0.05\times10^{-5}$	$1.14\pm0.04\times10^{-5}$	$6.5\pm0.8\times10^{-6}$	$1.46\pm0.22\times10^{-5}$
^{232}U	1.43×10^{-5}	$1.63\pm0.06\times10^{-5}$	$2.00\pm0.07\times10^{-5}$	---	$1.66\pm0.19\times10^{-5}$
Pb(nat)	0	$2.46\pm0.12\times10^{-7}$	$6.17\pm0.28\times10^{-7}$	---	$3.47\pm0.47\times10^{-6}$

*Calculated from cross sections and calibrated efficiency for neutrons

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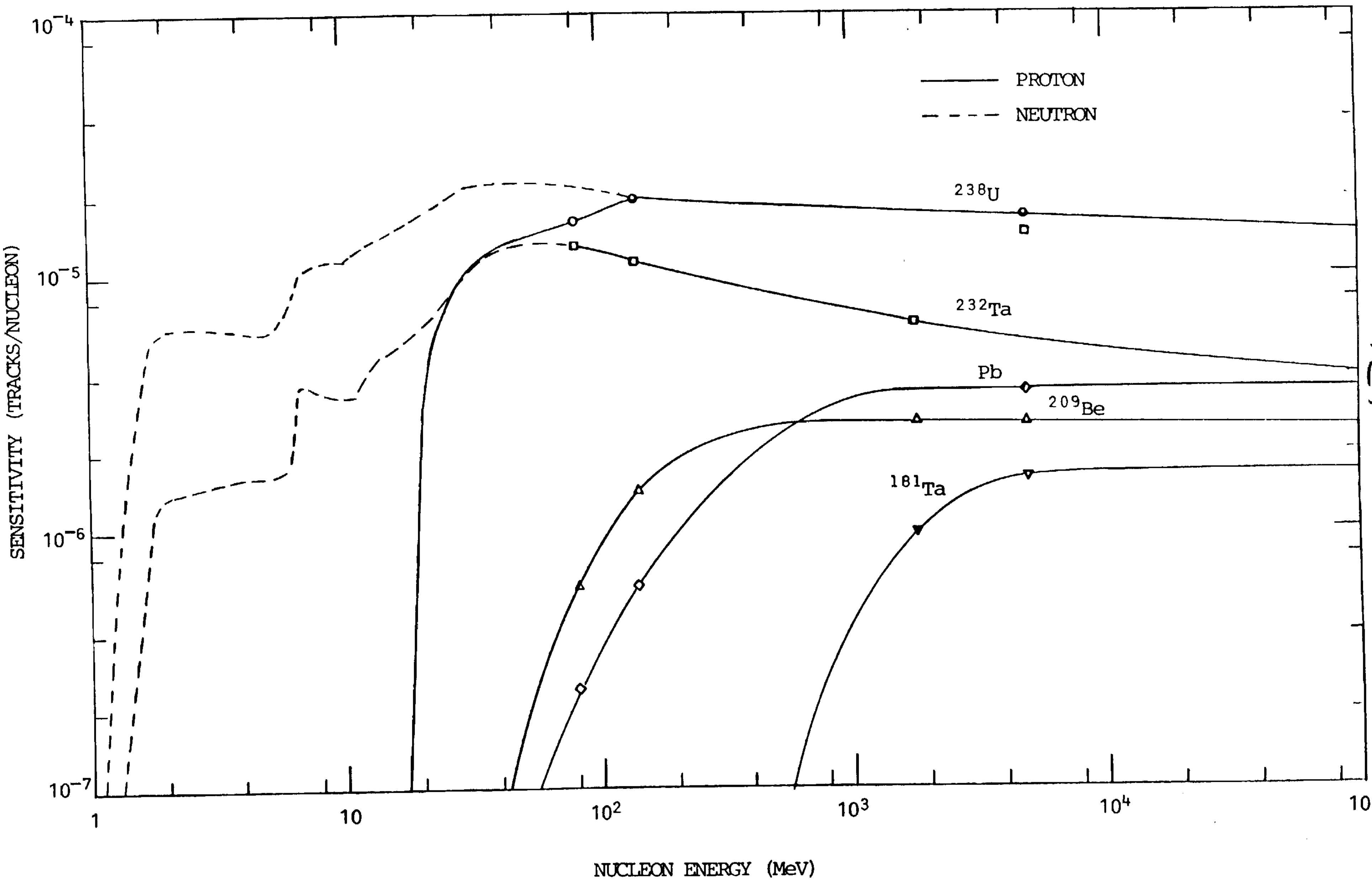

Fig. 3. Sensitivities of fission foil detectors to neutrons and protons